A framework to evaluate unified parameterizations for seasonal prediction: an LES/SCM parameterization test-bed

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LONG-TERM GOALS

The long term goals of this effort are (i) the development of a unified parameterization for the marine boundary layer; (ii) the implementation and evaluation of this new parameterization in the US Navy NOGAPS model; and (iii) the transition of this new version of the NOGAPS model into operations at Fleet Numerical Meteorology and Oceanography Center (FNMOC).

OBJECTIVES

The main goal of this particular project is to develop a framework to test and evaluate unified parameterizations in NOGAPS using Large-Eddy Simulation (LES) models. In particular we will: i) develop a Single Column Model (SCM) version of the latest operational NOGAPS that can be used to simulate GEWEX Cloud Systems Study (GCSS) case-studies; ii) use the LES developed at JPL to simulate the GCSS case-studies and to evaluate and develop parameterizations iii) develop an integrated framework to use the NOGAPS SCM and the LES model as a parameterization test-bed.

APPROACH

It is well accepted that sub-grid physical processes such as turbulence, convection, clouds, aerosols and radiation play an essential role in the accuracy of ocean-atmosphere coupled prediction systems. Unfortunately most of these small-scale processes are extremely difficult to represent (parameterize) in global models such as the Navy Operational Global Atmospheric Prediction System (NOGAPS). The Marine Boundary Layer (MBL) in particular is known to play the key role in regulating the interaction between the ocean and the atmosphere. A common strategy on how to tackle MBL parameterization development has been developed during the last 15 years by the GEWEX Cloud Systems Study (GCSS) working groups. In this project we will follow this GCSS strategy by creating a unified framework to develop and evaluate parameterizations in NOGAPS using high-resolution Large-Eddy Simulation (LES) models.

Key personnel:
J. Teixeira (JPL/Caltech) uses his expertise in cloud and boundary layer parameterizations to guide the development and implementation of the EDMF/PDF parameterization and its testing using LES models.

T. Hogan (NRL) uses his expertise in global modeling to assist with the investigations related to NOGAPS within the context of this ONR DRI.

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G. Matheou (JPL/Caltech) develops and implements the LES code in the context of the parameterization evaluation framework in the NOGAPS model.

WORK COMPLETED

LES simulations and utilization of LES data to evaluate and calibrate parameterizations.

i) LES simulations and NOGAPS evaluation in stratocumulus and cumulus GCSS cases;
ii) LES simulations and NOGAPS new parameterization evaluation in transition GCSS cases.

RESULTS

Implementation

The LES code numerically integrates the filtered (density-weighted) anelastic approximation of the Navier–Stokes (Ogura and Phillips, 1962). The base-state density ϱ0(z) is calculated from the hydrostatic balance at Θref and pref = 1000hPa. In the cases where the process of precipitation is included, the double-moment bulk microphysical parameterization of Seifert and Beheng (2001) is used. The fourth-order fully conservative advection scheme of Morinishi et al. (1998) is used to ensure that any dissipation arises purely from the subgrid scale closure. To preserve conservation of water, a second-order MC flux-limited scheme that ensures monotonicity is used to advect rain mass and raindrop number. Time is advanced using the low-storage third-order Runge–Kutta scheme of Spalart et al. (1991). The subgrid condensation scheme is all or nothing (e.g. Cuijpers and Duynkerke, 1993). The buoyancy-adjusted stretched-vortex subgrid-scale model (Misra and Pullin, 1997; Voelkl et al., 2000; Pullin, 2000; Chung and Matheou, 2012) is used to account for the unresolved turbulent physics. The horizontal boundaries are periodic and the top and bottom boundaries are impermeable with a 'sponge' region near the top boundary to minimize undesirable gravity wave reflection.

Unlike previous LES applications in simulations of atmospheric boundary layers, the present LES is used to simulate a diverse set of conditions without any tuning or change in the setup. In the following pages, results for various cases are briefly documented. In all these cases the model setup is identical, the only difference is initial and boundary conditions, and large-scale forcing.

A main aspect of the simulations reported here is the performance of the implementation as the grid resolution changes. This is a consistency check, that although simple in nature, it is difficult to achieve in practice. The LES predictions of the present framework exhibit good resolution independence, even for grids that are typically considered coarse.

BOMEX case: Shallow cumulus convection

Trade-wind non-precipitating cumulus-topped boundary layer. Conditions correspond to the BOMEX campaign. The setup of the case and model inter-comparison is detailed in Siebesma et al. (2003). The domain size is 20.482 × 3 km3. Three grid resolutions were used at Δx = 20, 40, and 80 m.

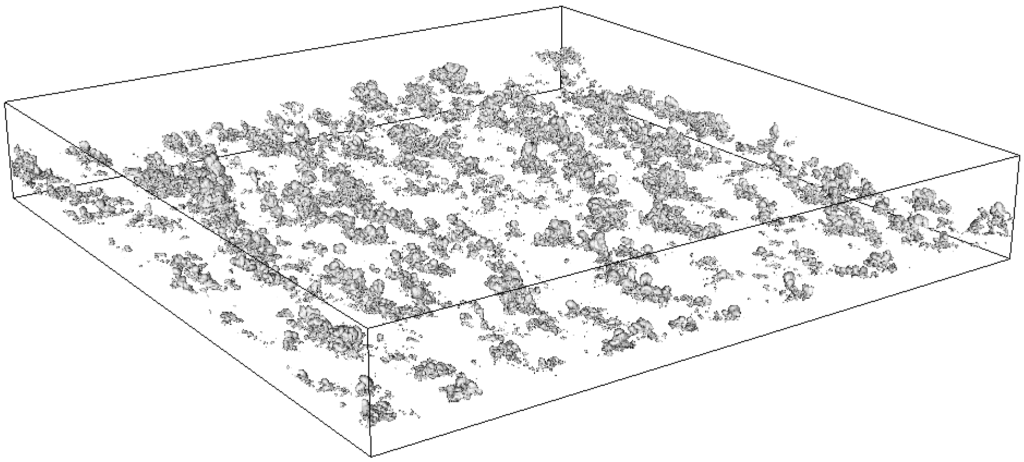

Figure 1: Shallow cumulus clouds during BOMEX after 12 hours of simulation with 20m resolution.

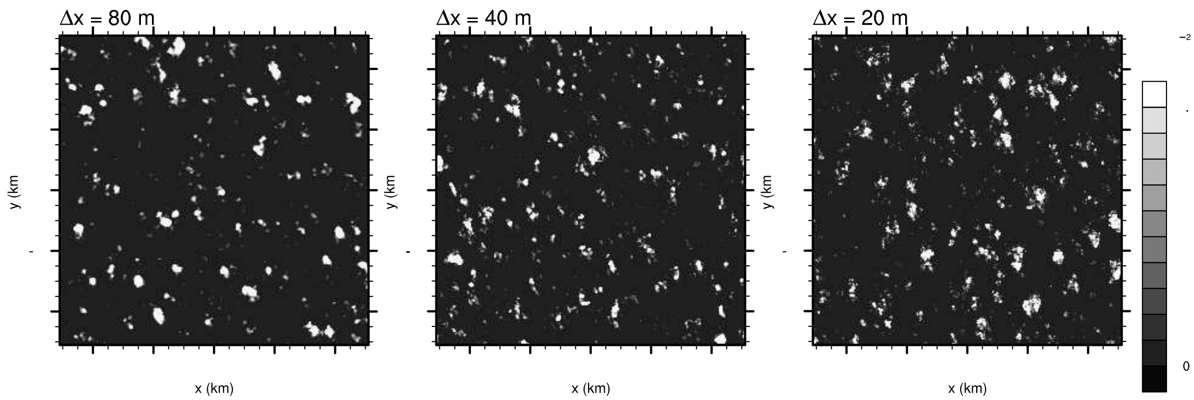

Figure 2: BOMEX liquid water path at t=12 hours.

RICO Case: Shallow precipitating cumulus

Trade-wind precipitating cumulus-topped boundary layer. Conditions correspond to the RICO campaign (Rauber et al., 2007). The setup of the case and model inter-comparison is detailed in VanZanten et al. (2011). The domain size is 20.482 × 4 km3. Three grid resolutions were used at Δx=20, 40, and 80 m.

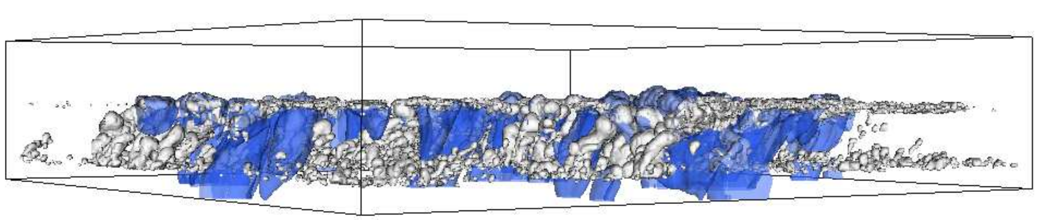

Figure 3: RICO Clouds and rain (blue isosurfaces) at t=24 hours for simulation with 40 m resolution.

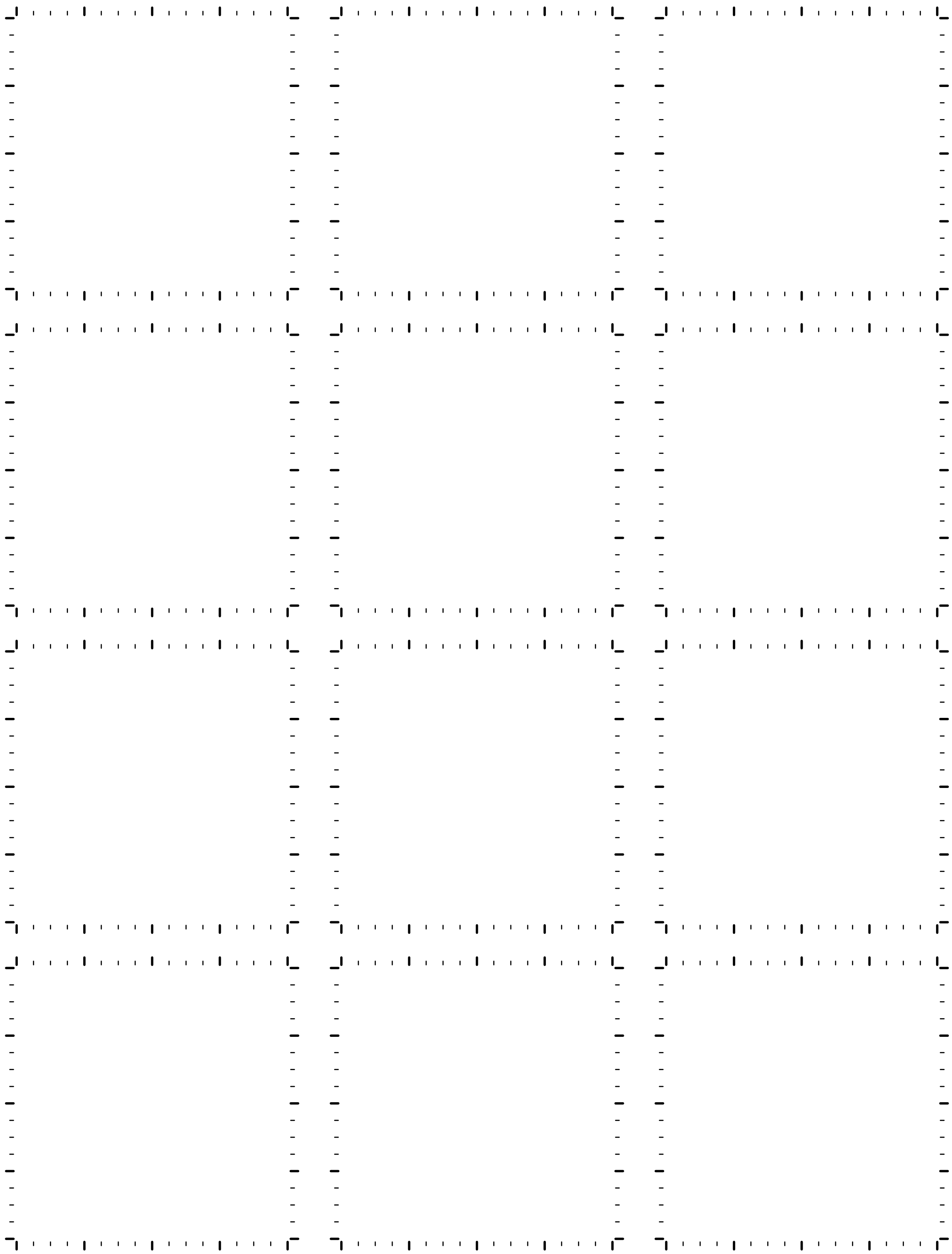

Figure 4: Evolution of the cloud structure in the boundary layer as precipitation develops. The panels from left–right top–bottom show instances of cloud liquid water path separated by 1 hour. The domain is 80.2×5 km3.

DYCOMS-II: Nocturnal marine stratocumulus

Stratocumulus-topped boundary layer corresponding to the first research flight (RF01) of the second Dynamics and Chemistry of Marine Stratocumulus (DYCOMS-II) field study. The setup follows that of Stevens et al. (2005) with the exception of the surface fluxes. The surface fluxes are computed using the Monin–Obukhov theory with Charnock's roughness length (Charnock, 1955). The grid spacing is $\Delta x = \Delta y = \Delta z = 5$ m and $\Delta x = \Delta y = \Delta z = 2.5$ m.

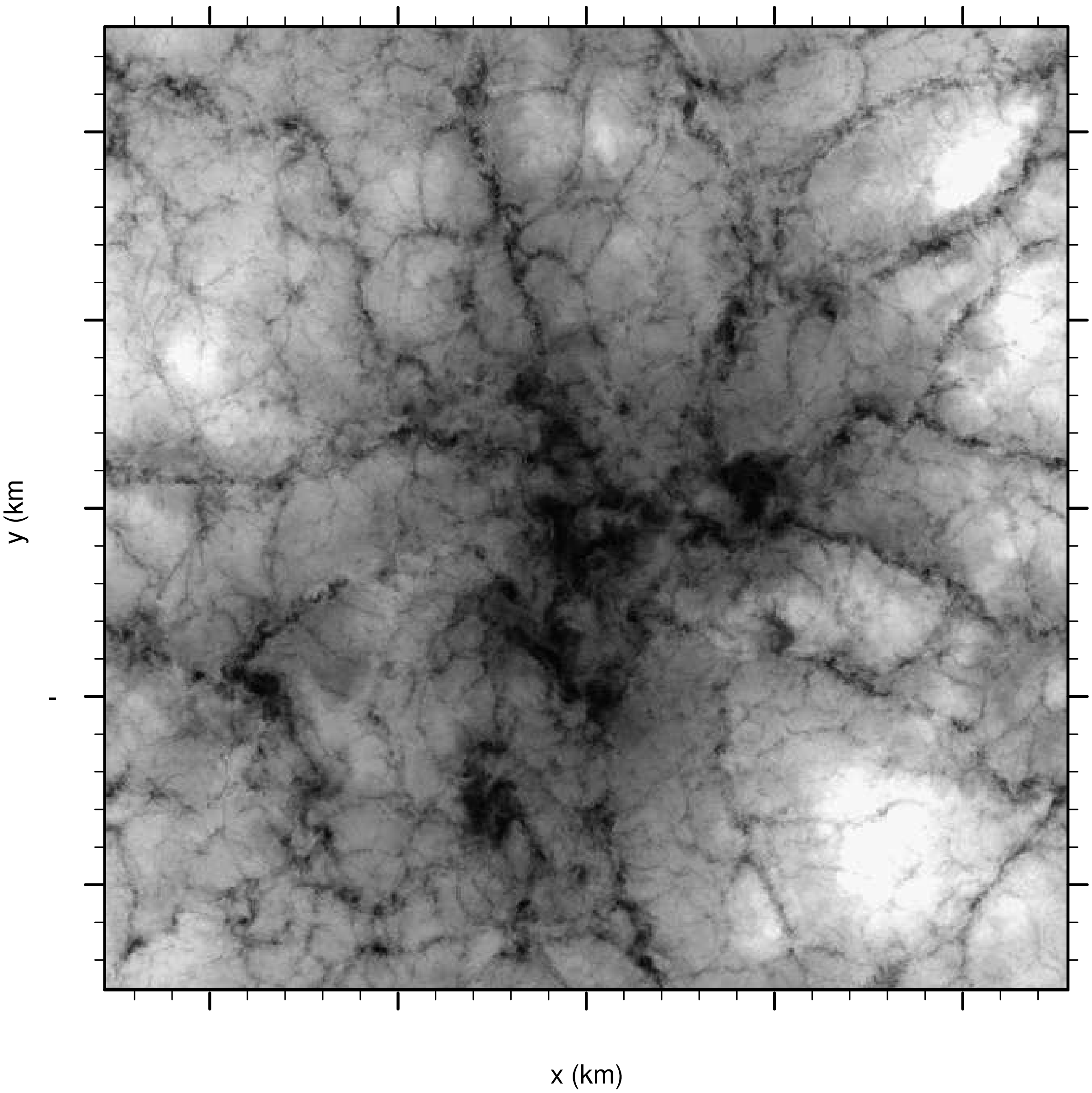

Figure 5: DYCOMS-II liquid water path at t=4 hours for a resolution of 2.5 m.

IMPACT/APPLICATIONS

These results have an important potential future impact for the weather prediction capabilities of the US Navy after the implementation of these new parameterizations in the NOGAPS model. In addition

it will be the first time that a unified parameterization of the marine boundary layer has ever been developed and implemented in a global weather prediction model.

TRANSITIONS

The new EDMF parameterization will be proposed for a transition at FNMOC after implementation and adequate testing in the NOGAPS model using the LES approach.

RELATED PROJECTS

This project is part of the "Unified Physical Parameterizations for Seasonal Prediction" Departmental Research Initiative.

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